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Land application of poultry litter and water quality in Oklahoma, U.S.A.

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Abstract

With the rapid growth of the poultry industry in Oklahoma, U.S.A., more litter is applied to farm land. Thus, information is required on the impact of applications on regional soil and water resources. The effect of soil and poultry litter management on nitrogen (N) and phosphorus (P) loss in runoff and subsurface flow from four 16 m^2 plots (Ruston fine sandy loam, 6 to 8% slope) was investigated under natural rainfall. Plots under Bermudagrass (*Cynodon dactylon*) received 11 Mg litter ha^{-1}, which amounts to contributions of approximately 410 kg N and 140 kg P ha^{-1} yr^{-1}. In spring, litter was broadcast on 3 of the plots; the upper half of one and total area of the other two. One of the total-area broadcast plots was tilled to 6 cm, the other remained as no till. The fourth plot served as a control. Relative to the control, litter application increased mean concentrations of total N and total P in runoff during the 16-week study for no-till (15.4 and 5.8 mg L^{-1}) and tilled treatments (16.7 and 6.1 mg L^{-1}). However, values for the half-area application (5.6 and 2.0 mg L^{-1}) were similar to the control (5.7 and 1.3 mg L^{-1}). Interflow (subsurface lateral flow at 70 cm depth) P was not affected by litter application; however, nitrate-N concentrations increased from 0.6 (control) to 2.9 mg L^{-1} (no till). In all cases, < 2 % litter N and P was lost in runoff and interflow, maintaining acceptable water quality concentrations. Although litter increased grass yield (8518 kg ha^{-1}) compared to the control (3501 kg ha^{-1}), yields were not affected by litter management. An 8-fold increase in the plant available P content of surface soil indicates long-term litter management and application rates will be critical to the environmentally sound use of this nutrient resource.

Introduction

In recent years, poultry production in eastern Oklahoma has experienced tremendous growth. From an economic standpoint, total broiler production increased from 165×10^6 to 239×10^6 kg yr^{-1} between 1987 and 1989 in Oklahoma, representing an increase in the value of production from USD105 to USD198 million (Doye *et al.*, 1991; National Agricultural Statistics Service, 1989). This is a 47% increase in production over a two-year period, hence, it is apparent that poultry production in eastern Oklahoma is becoming increasingly important to the economic well-being of the area.

A growing concern of this industry is the utilization of the concentrated animal manure that accumulates in production systems. In broiler production, manure plus the bedding material (usually pine shavings or wheat straw in Oklahoma), is broadcast as poultry litter on pasture or cropland. Poultry litter is considered one of the best sources of organic fertilizers available, as well as an alternative to mineral fertilizers. However, excessive applications of litter can result in negative environmental impacts. Nitrate-nitrogen (NO_3-N) leaching into the ground water, phosphorus (P) runoff into surface waters, and release of pathogenic micro-organisms are three of the main problems encountered with improper management of this resource.

Continual land application of poultry litter at rates in excess of crop requirements has resulted in NO_3-N movement through the soil into ground water (Cooper *et al.*, 1984; Mcleod and Hegg, 1989). The fate of litter P in soil and its movement in soil water flow has received less attention because of public focus on NO_3-N contamination of ground water supplies. Nonetheless, the application of poultry litter can result in increased soil P availability and decreased P sorption within the soil profile (Field *et al.*, 1985; Reddy *et al.*, 1980).

Impact assessments of long-term poultry litter application on soil and water resources in eastern Oklahoma indicate N and P levels increase within the surface 5 cm of soil, making them more susceptible to loss in runoff (Sharpley *et al.*, 1991; Sharpley *et al.*, 1993). Average 1.2- and 2.5-fold increases in the total N (TN) and NO_3-N content of treated compared with untreated 0- to 100-cm soil profiles were observed by Sharpley *et al.*(1993) in several eastern Oklahoma soils. They also noted that due to the large amount of P added in litter, the capacity of the soil to sorb further additions of P was lower in the surface 30 cm of the treated than untreated soil.

In order to devise reliable recommendations for land application of poultry litter and management alternatives, information is needed on the fate and transport of N and P applied in poultry litter to soil and the associated impacts on soil and water resources. The objective of this paper was to examine the fate of N and P applied in poultry litter under field conditions, natural rainfall, and three management practices.

Materials and methods

Experimental plots

Poultry litter was applied to three of four adjacent experimental field plots at the National Agricultural Water Quality Laboratory in Durant, OK. On May 27, 1992 (Julian day 148) Bermudagrass (*Cynodon dactylon*) has been established on these plots for several years. The soil type was Ruston fine sandy loam (*Typic Paleudult*) with 6 to 8% slope, consisting of three natural horizons having a total thickness of about 70 cm. Each plot was approximately 2.0 m wide by 8.0 m in length (Fig. 1). A narrow walkway separated Plots 2 and 3, which allowed easy access to the two center plots. The plots were isolated from each other and adjacent areas by sheetmetal plates extending 15 cm above ground to 90 cm below ground.

Prior to poultry litter application, bermuda grass on all plots was trimmed to within 5 cm of the soil surface on May 21, 1992 (Julian day 142). The grass was not cut again until August 25, 1992 (Julian day 238), at which time it was harvested for plant yield and nutrient content. Poultry litter was broadcast by hand over Plots 1, 2, and 3 in 90 cm × 200 cm sections with the slope. Litter was applied to small sections at a time to ensure uniform coverage. Three different management techniques of broadcast litter applications were used on Plots 1, 2, and 3 (Fig. 1). Plot 1 received half-area application (half area), Plot 2 — total area application with incorporation (tilled), and Plot 3 — total area application with no-tillage (no till). The rate of application was 11 mg ha^{-1} (5 t $acre^{-1}$), a level commonly used annually by poultry producers in eastern Oklahoma.

On Plot 1, 22 mg ha^{-1} of litter was broadcast on the upper half area of the plot only. Thus, Plot 1 received the same total amount of litter as Plots 2 and 3 but on half the area. Applying the litter in this manner would indicate whether the presence of a buffer zone between the applied area and the point of discharge reduces nutrient concentrations in runoff or interflow. After broadcasting the poultry litter on Plot 2, the plot was hand-tilled to a depth of 6 cm, thus incorporating the litter into the soil surface. Plot 4 received no litter and served as the control plot for collection of background data. During the study period from May to September 1992, 90 cm of natural rainfall was the only source of water the plots received. This compares to a long term average of 60 cm. Consequently, the results reflect an above normal rainfall condition.

Litter, soil and water flow

Poultry litter (pine-bark shavings bedding material) was collected on the day of land application from a broiler house in McCurtain Co., southeastern Oklahoma. The sample was thoroughly mixed and stored at "house moisture" in plastic bags at 4 °C, until applied to the plots 4 days after collection. The moisture content of the litter was determined by gravimetric analysis, for correction of N and P contents. The "house moisture" content for the litter was 9.8%.

Soil samples were collected at 5-cm intervals to a 50-cm depth, prior to poultry litter application in April and towards the end of the growing season on September 17, 1992 (Julian day 261). Soil samples were air-dried and sieved (< 2 mm) prior to storage and N and P analysis.

Total surface runoff and subsurface flow (interflow) to a depth of 70 cm were collected from individual plots

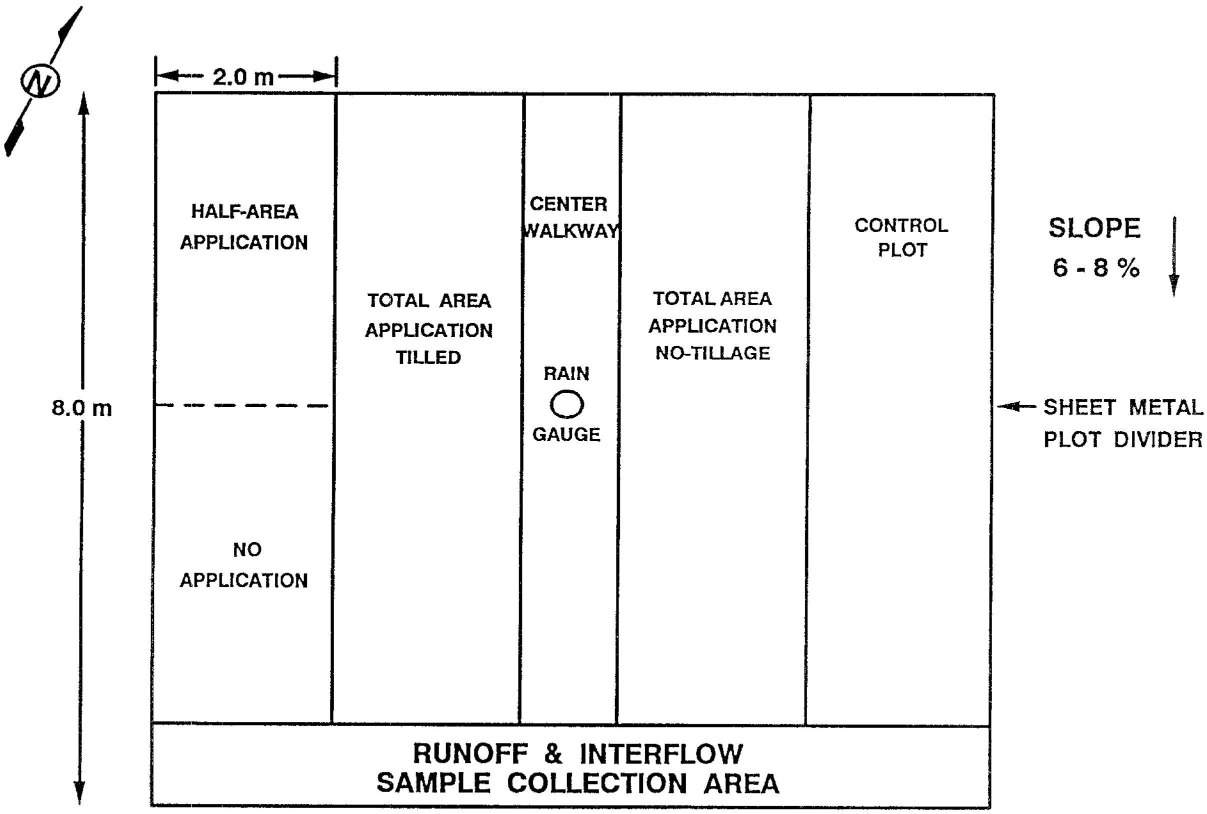

Fig. 1. Schematic of sloping field plots and poultry litter application treatments.

downslope in a large subsurface roofed collection area (Fig. 1). During each rainfall event a collection system diverted runoff and subsurface flow to separate large metal containers from which total volumes of flow were measured and subsamples collected for chemical analysis and determination of sediment loss. Total rainfall (cm) was measured after each event.

Chemical analyses

The TN and total P (TP) contents of soil and litter applied to the plots, were determined by a semimicro-Kjeldahl procedure (Bremner and Mulvaney, 1982). The TP content of the Kjeldahl digest extract of leachate was measured by the colorimetric method of Murphy and Riley (1962). Soil NO_3–N was determined using procedures described by Keeney and Nelson (1982). Available soil P content was determined using the Mehlich-3 procedure, where 1 g of soil is shaken end-over-end with 10 mL 0.2 *M* CH_3COOH, 0.25 *M* NH_4NO_3, 0.15 *M* NH_4F, 0.013 *M* HNO_3, and 0.001 *M* EDTA for 5 min (Mehlich, 1984).

Litter TN and TP contents were 44 and 15 g kg^{-1}, respectively. These values are similar to mean TN (41 g kg^{-1}) and TP (14 g kg^{-1}) contents of poultry litter reported by Edwards and Daniel (1992) from a review of published data.

Aliquots of each runoff and interflow sample were filtered (< 0.45 μm) prior to NO_3–N, ammonium-N (NH_4–N), and soluble inorganic P (SP) determinations, while total Kjeldahl N (TKN), TP, and bioavailable P (BAP-algal available P) were determined on unfiltered samples. Nitrate–N, NH_4–N, TKN, and TP were analyzed by standard automated methods described in Methods for Chemical Analysis of Water and Wastes (USEPA, 1979). Total N was calculated as the sum of NO_3–N and TKN. Soluble P was determined using the colorimetric method of Murphy and Riley (1962). Particulate P (PP) was calculated as the difference between TP and SP. Bioavailable P concentration was determined by using iron oxide-impregnated paper strips (Sharpley, 1993). The strips were prepared by immersing filter-paper circles (15-cm diam., Whatman No. 50 or S&S 589 red ribbon —

small pore size < 5 μm) in a solution containing 10 g $FeCl_3 \cdot 6H_2O$ in 100 mL distilled water. The paper circles are air dried and immersed in 2.7 *M* NH_4OH solution to convert $FeCl_3$ to Fe oxide. After the paper circles are air dried, they are cut into strips 10 by 2 cm and stored for subsequent use.

The BAP content of runoff is determined by shaking 50 mL of unfiltered runoff with one Fe-oxide strip for 16 h. The strip is then removed, rinsed free of adhering soil particles, and air dried. Phosphorus retained on the strip is removed by shaking the strip end-over-end with 40 mL of 0.1 *M* H_2SO_4 for 1 h and measured by the method of Murphy and Riley (1962). Suspended sediment concentration of runoff and interflow was determined by gravimetric analysis following evaporation to dryness (378 K) of duplicate 250-mL aliquots of unfiltered samples.

The plots were not replicated due to a lack of space and natural spatial variability. However, 11 successive runoff events were used as replicates of treatment effects. Differences in N and P transport in surface runoff between plots were statistically evaluated using analysis of variance for paired data. Interflow was not statistically evaluated due to the erratic nature of interflow from the plots.

Results and discussion

Runoff and interflow samples from each plot, collected from nine events over two years prior to litter application, were used to characterize background concentrations of N and P. Over this period, runoff averaged 299 and interflow 356 m^3 ha^{-1}. No significant difference ($p > 0.05$) in N and P concentrations were found between the four plots. Averaged for all plots and events, TN was 2.85, NO_3–N 0.30, NH_4–N 1.41, TP 0.81, SP 0.02, and BAP 0.05 mg L^{-1} in surface runoff. Mean interflow concentration of TN was 1.15, NO_3–N 0.54, NH_4–N 0.40, TP 0.54, SP 0.01, and BAP 0.03 mg L^{-1}.

Nitrogen

Runoff. The concentrations of TN in runoff showed periodic increases throughout the study with till and no-till plots having the highest peak values (40 and 39 mg L^{-1}, respectively) (Fig. 2). Total N concentrations in runoff were lower than the other treatments and were similar to control values (Fig. 2). The periodic increase in TN in runoff may have been due to the combined effect of intense storms and high antecedent moisture conditions. The sporadic NO_3–N peaks in runoff from the tilled plot (as high as 15.2 mg L^{-1}, Fig. 2) indicate NO_3–N loss in runoff during intense rainfall events. Nitrate–N concentrations in runoff from other plots were comparatively low (0.04 – 3.14 mg L^{-1}).

Total soil loss, average concentrations, and amounts of N collected in runoff and interflow during the study period are presented in Table 1. A significant increase (p <0.05) in mean TN concentrations in runoff was measured from the tilled and no-till plots compared to the control and half-area plots during the study period (Table 1). Half-area application maintained TN concentrations in runoff near control levels. There was no significant difference between mean concentrations of TN in runoff from tilled (16.7 mg L^{-1}) and no-till (15.4 mg L^{-1}) plots. Mean NO_3–N concentrations in runoff were higher from all treated plots compared to the control, with concentrations being highest from the tilled plot (4.2 mg L^{-1}).

The data for mass loss of N show somewhat different data trends due to differing runoff volume from each plot (Table 1). The variable flow rates between plots were due to the combined effects of management practice, variable infiltration rates, and differences in the percolation rates at deeper depths in the soil profile. Maintaining the plots under the same management systems for several consecutive years should provide sufficient data to take into account these differences in flow volumes.

Interflow. Statistical analysis of interflow data was not possible due to the unequal number of samples collected (from 3 to 11 events) during the study period and the fact that interflow did not occur from all plots during some events. The values in Table 1 reflect these differences in flow and subsurface lateral movement of solute from the plots. However, mean concentrations for both TN and NO_3–N in interflow were higher for treated than control plots. This is also illustrated in Figure 2. In contrast to surface runoff, TN and NO_3–N concentrations from the half-area application were higher than the control and comparable to the till and no-till plots (Fig. 2). This suggests that in the applied area, N moved into the soil profile and then laterally along the slope and through the untreated portion of the plot.

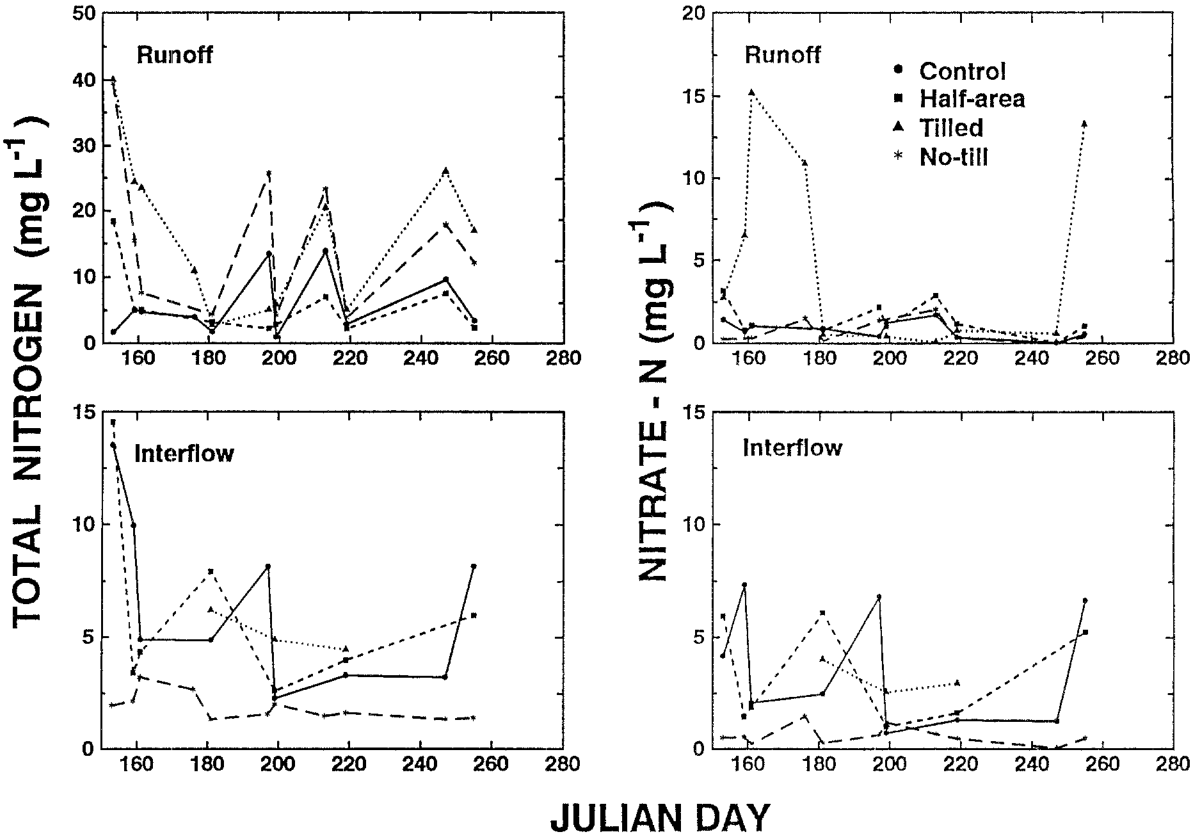

Fig. 2. Total N and NO_3-N concentration of runoff and interflow during the study period for each treatment.

Table 1. Nitrogen and soil loss in runoff and interflow from the control and treated field plots during the study period.*

Treatment	Total flow $m^3\ ha^{-1}$	Soil loss $kg\ ha^{-1}\ yr^{-1}$	Concentration ($mg\ L^{-1}$) TN	NO_3-N	NH_4-N	Amount ($kg\ ha^{-1}\ yr^{-1}$) TN	NO_3-N	NH_4-N
RUNOFF								
Control	929	202.9	5.74 a	0.53 a	1.99 ab	3.35	0.27	1.38
Tilled	664	117.4	16.70 b	4.02 b	4.78 b	4.72	1.08	1.43
No-till	397	69.8	15.40 b	1.41 ab	4.36 b	2.41	0.16	0.53
Half-area	832	174.8	5.56 a	0.83 a	1.05 a	3.92	0.80	0.87
INTERFLOW								
Control	593	64.2	1.83	0.57	0.55	1.11	0.34	0.33
Tilled	284	82.9	4.20	2.41	0.90	1.22	0.70	0.26
No-till	65	69.0	5.02	2.93	0.34	0.34	0.20	0.02
Half-area	380	110.8	3.93	1.85	0.51	1.66	0.78	0.22

* Values followed by the same letter indicate no significant difference between means as determined by analysis of variance for paired data ($p < 0.05$).

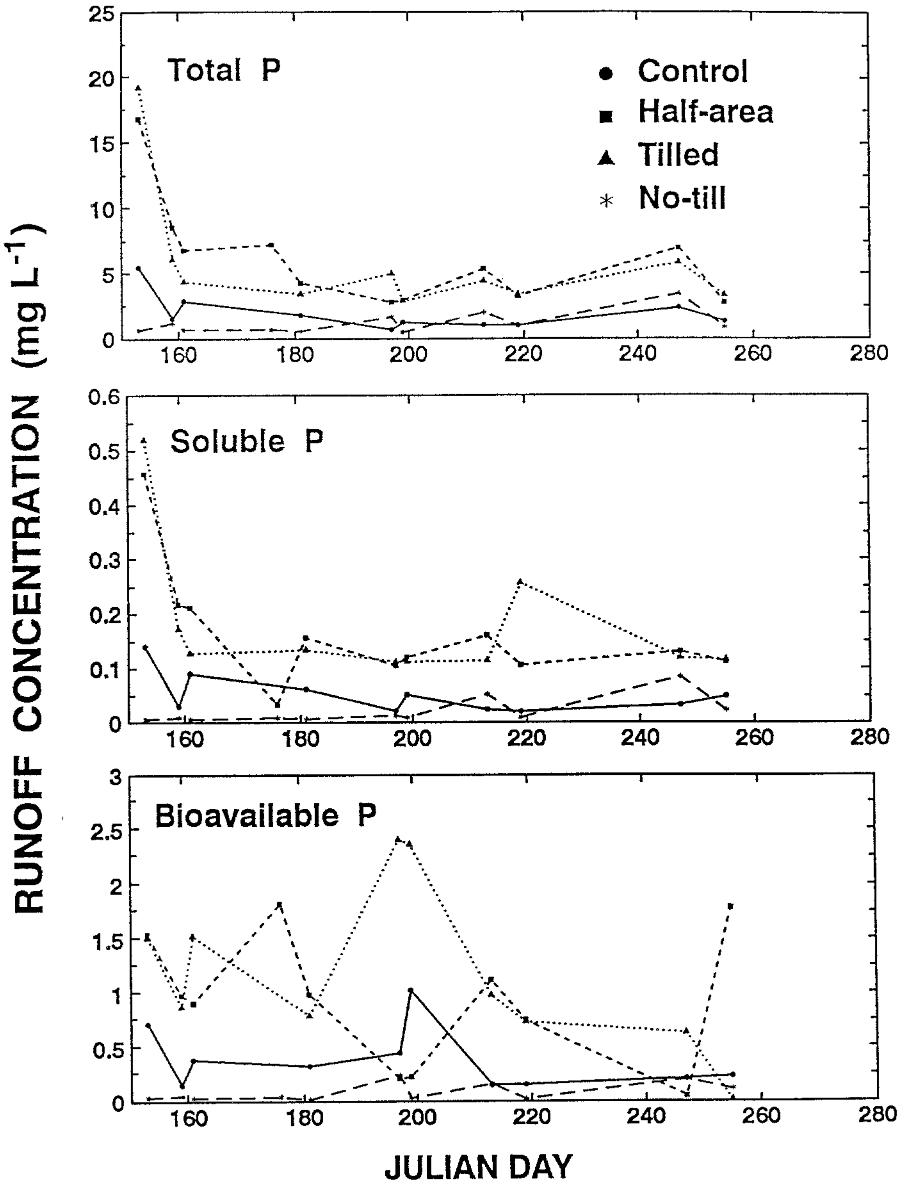

Fig. 3. Total, soluble and bioavailable P concentration of runoff during study period for each treatment.

Phosphorus

Runoff. Unlike N, maximum TP and SP concentrations occurred in the first runoff, one day after litter application (Fig. 3). Maximum TP concentrations in runoff from the different plots were: 6.0 mg L^{-1} for half-area, 17.0 mg L^{-1} for tilled, and 19.5 mg L^{-1} for no-till. For SP, corresponding values were: 0.15 mg L^{-1}, 0.45 mg L^{-1}, and 0.52 mg L^{-1}. Following these peaks, there was a general decrease in TP and SP concentration with time. Even so, TP and SP concentrations were still greater than from either the control or half-area plots, 10 runoff events and 110 days after litter application (Fig. 3). Runoff P concentrations from the control plot were lower than from the other plots and showed little variation with time. Half-area application reduced TP, SP, and BAP concentrations of runoff compared to total area applications, with the greatest effect observed immediately after litter application.

Table 2. Phosphorus loss in runoff and interflow from the control and treated field plots during the study period.*

Treatment	Concentration (mg L^{-1})			Amount (kg ha^{-1} yr^{-1})		
	TP	SP	BAP	TP	SP	BAP
RUNOFF						
Control	1.27 a	0.02 a	0.09 a	0.91	0.01	0.04
Tilled	6.06 b	0.18 b	0.91 bc	2.96	0.10	0.16
No-till	5.80 b	0.18 b	1.19 c	0.77	0.07	0.69
Half-area	1.95 a	0.05 a	0.48 ab	1.70	0.05	0.44
INTERFLOW						
Control	0.55	0.02	0.04	0.34	0.01	0.02
Tilled	0.70	0.02	0.05	0.21	0.00	0.02
No-till	0.74	0.02	0.40	0.05	0.00	0.03
Half-area	0.74	0.02	0.07	0.31	0.01	0.03

*Values followed by the same letter indicate no significant difference between means as determined by analysis of variance for paired data ($p < 0.05$).

Table 3. Bermudagrass yield and N and P uptake for the four plots 14 weeks after poultry litter application.

Treatment	Yield	Content		Uptake	
		N	P	N	P
	kg ha^{-1}	g kg^{-1}		kg ha^{-1}	
Control	3501	6.84	1.70	23.9	5.9
Half Area	8213	7.81	2.26	64.2	18.6
Tilled	8515	8.71	2.03	74.1	17.3
No till	8114	9.15	2.09	74.2	16.9

Table 4. Nitrogen and P content of surface soil (0–5 cm) from the four plots 16 weeks after litter application.

Treatment	Total N	Nitrate-N	Total P	Mehlich 3 P
	mg kg^{-1}			
Control	1099	9	243	16
Half-area				
Upper	1894	16	412	131
Lower	1076	8	299	21
Tilled	1696	25	350	85
No-till	1374	33	350	86

No difference ($p > 0.05$) in TP, SP, and BAP between the control or half-area treatments or between till and no-till was observed (Table 2). However, half-area application of litter significantly ($p < 0.05$) reduced the TP and SP concentration of runoff compared to till and no-till plots (Table 2). The effect of litter management on BAP concentration was less consistent than for TP or SP.

Particulate P constituted the major portion (> 97%) of TP transported in runoff from all treatments, including the control (Table 2). However, BAP (comprised of SP and a variable portion of PP) accounted for 15% of TP for tilled, 21% for no-till, and 25% for half-area application, but only 7% for the control. Thus, poultry litter application not only increased P loss in runoff but the bioavailability of P transported.

Interflow. Total P, SP, and BAP concentrations in interflow were low and similar between all plots (Table 2). This indicates that during the first year poultry litter application had a negligible effect on P loss in interflow.

Plant and soil effects

Poultry litter application increased grass yield more than two fold on all plots receiving litter compared to the control plot (Table 3). The N and P content of Bermudagrass receiving no litter (control) was lower ($p < 0.05$) than on plots receiving litter (Table 3). As a result, N and P uptake was about 3 times greater with each litter treatment compared to the control (Table 3).

Even so, uptake of N and P by Bermudagrass amounted to only 12 and 8% of that added in litter.

In mid-September, 16 weeks after litter application and 2 d after the grass had been harvested, the TN and TP content of surface soil (0–5 cm depth) from plots treated with poultry litter, was greater than the control plot (Table 4). Till and no-till average TN content was 282 mg kg^{-1} higher than the control. In the applied area of the half-area plot, TN content was 795 mg kg^{-1} higher than in the control. For all treatments, TP contents were greater than the control (Table 4). Similarly, plant available P (Mehlich-3 P) was increased following poultry litter application (Table 4). Although Mehlich-3 P contents of the 0–5 cm of soil from tilled (85 mg kg^{-1}) and no-till (86 mg kg^{-1}) plots were similar, levels for the half-area treatment receiving litter were greater (131 mg kg^{-1}). Thus, appreciable residual Mehlich-3 P had built up compared to the control (16 mg kg^{-1}). Below the 10-cm depth there was no effect of poultry litter application on soil N or P content.

The TN, NO_3-N, TP, and Mehlich-3 P contents of surface soil for the half-area treatment receiving no litter were similar to the control plot (Table 4). This indicates little movement and trapping of litter N and P downslope by the untreated half-area.

The accumulation of N and P in the surface 5 cm of soil, following litter application, emphasizes the need to conduct long-term field studies of poultry litter's impact on water quality. With continual land applications of litter, annual carry over of N and P remaining in surface soil in excess of plant needs, will increase the potential for N and P transport in surface runoff and interflow in subsequent years.

Conclusions

Poultry litter application increased total N in runoff and interflow, and NO_3-N loss in interflow. Half-area application reduced N levels in runoff compared to till and no-till plots but not in interflow. Although NO_3-N levels in interflow increased with poultry litter application on all treated plots, concentrations did not exceed 10 mg L^{-1}. Poultry litter application increased P loss in runoff from all treated plots; however, P loss was reduced by half-area litter application. Litter application had no effect on P loss in interflow. Overall, less than 2% of the N and P applied in litter was lost in runoff and interflow. Even so, broadcast applications of poultry litter with or without incorporation increased P loss in runoff for up to 16 weeks after application.

Grass yield was increased by more than a factor of two and N and P uptake by a factor of three as a result of poultry litter application. For all treatments, only 12% N and 8% P added in poultry litter was taken up by Bermudagrass. Considering both the amounts of N and P lossed in water flow and taken up by grass, most of the litter N and P remained in the soil (> 80%). Crops of higher or lower nutrient requirements may reduce or increase the carry-over of residual litter N and P at the end of the growing season. Use of high nutrient requirement crops may, thus, decrease the potential for N and P loss in runoff and interflow. Soil analyses indicated an increase in soil TN, TP, and plant available P only in the top 5 cm of soil 16 weeks after litter application. Below a soil depth of 10 cm there was no residual effect of litter application.

The results of this study suggest that the rate and timing of poultry litter application, antecedent moisture content prior to a rainfall event, and untreated buffer areas are all important factors which affect the release and transport of N and P in runoff and interflow from lands receiving poultry litter. Consideration of these factors in combination with proper management should minimize the loss of N and P associated with poultry litter application, and maintain downstream water quality within acceptable limits. Further, to determine long-term effects of poultry litter application, this experimental project will be repeated annually for the next five years under the same management practices.

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